CURious Variables Experiment (CURVE). CCD Photometry and Variable Stars in the field of open cluster NGC 637

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ABSTRACT

We present VI photometry for the open cluster NGC 637 which is located in the Cassiopeia region. Morphology of cluster color-magnitude diagram indicates that it is a young object with age of a few million years. The apparent distance modulus of the cluster is $13.9<(m-M)_V<14.3$, while reddening is $0.69<E(V-I)<0.73$. We estimated the heliocentric distance as $2.6<d<3.3$ kpc. We also report the identification of two variable stars in NGC 637. One of the variables is a non-radial pulsating β Cep-type star. Other one is a likely ellipsoidal variable, however its pulsating nature can not be excluded.

Hertzsprung-Russell (HR) and C-M diagrams – Stars: variables : beta Cep – open clusters and associations: individual: NGC 637

1 Introduction

CURious Variables Experiment (CURVE) is a long-term project focused on observations of open clusters, globular clusters and cataclysmic variable stars in the northern hemisphere (Olech *et al.* 2003a, Olech *et al.* 2003b). In stellar clusters we principally search for variable objects. However, our data also allow to estimate basic parameters of observed clusters, such as distances and ages.

NGC 637, also known as C 0139+637 or OCl 329, is a not very abundant open cluster situated in the Cassiopeia region of the Perseus spiral arm of our Galaxy (l=128$^\circ\!\!.$55, b=+1$^\circ\!\!.$73). The first photometric studies of this cluster were done by Grubissich (1975) in RGU system. He estimated reddening and distance to the cluster. Later, Huestamendia *et al.* (1991) published photoelectric UBV observations and assessed age of the cluster as 15 Myr. NGC 637 was also observed by Phelps and Janes (1994) as one of 23 open clusters to explore the star formation history of the Cassiopeia region. They found that the previous authors had overestimated the age of the cluster and suggested NGC 637 to be 0-4 Myr old.

This paper presents CCD VI photometry and results of a year-long monitoring of NGC 637 in search for variable objects. We also give characteristic parameters of the cluster.

2 Observations and Reductions

Observations of the open cluster NGC 637 were made during 52 nights between January 29, 2004 and December 11, 2004 at the Ostrowik station of the Warsaw University Observatory. The data were collected using the 60-cm Cassegrain telescope equipped with a Tektronics TK512CB back-illuminated CCD camera. The scale of the camera was $0''.76$/pixel providing a $6'.5 \times 6'.5$ field of view. The full description of the telescope and camera was given by Udalski and Pych (1992).

We monitored the cluster using standard Johnson-Cousins VI filters and also in "white light". The exposure times were from 120 to 240 seconds. In total, we obtained 124, 234 and 591 images in V, I and white light, respectively. The median seeing was $4''.03$, $4''.06$ and $3''.90$, respectively. The map of the observed region is shown in Fig. 1.

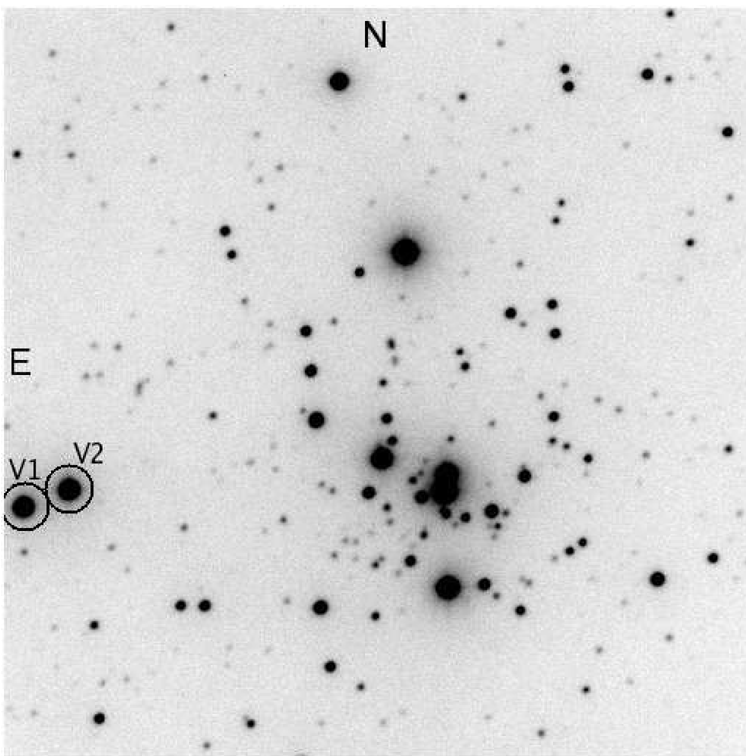

Fig. 1. Map of NGC 637 based on a white light image taken with 180 sec exposure. The field of view is about 6.5×6.5 arcmin^2. Detected variable stars are marked by circles.

All images were de-biased, dark current subtracted and flat-fielded using the IRAF * package. For the white light images the photometry was extracted with the help of a slightly modified ISIS-2.1 image subtraction package (Alard and Lupton 1998). Our procedure followed that described in detail by Mochejska *et al.* (2002). A reference frame was constructed by combining 23 individual images taken during dark time on the night of 2004 Sep 18/19. The seeing for the resultant reference image was FWHM=2.88 arcsec. Profile photometry for the reference frame was extracted with DAOPHOT/ALLSTAR (Stetson 1987).

*IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

These measurements were used to transform the light curves from differential flux units into instrumental magnitudes.

For the V and I band images we derived classical profile photometry. In each filter we selected one image as a reference and calculated the median value of the magnitude offset for each individual frame in respect to the reference image. Subsequently, we constructed light curves for all stars retained on lists corresponding to the reference image.

All light curves were analyzed in a search for variable stars. This was performed with the TATRY code using multiharmonic periodogram of Schwarzenberg-Czerny (1996). Periodograms were calculated for periods ranging from 0.05 to 500 days, and the light curves examined by eye.

We perform an elimination of some potentially poor measurements in lists of stars extracted from V and I reference frames. A few objects with unusually large errors of photometry, *i.e.*, with large values of CHI and SHARP parameters, returned by DAOPHOT, were rejected. Fig. 2 displays the *rms* deviation as a function of magnitude in V and I bands for 181 and 284 stars, respectively.

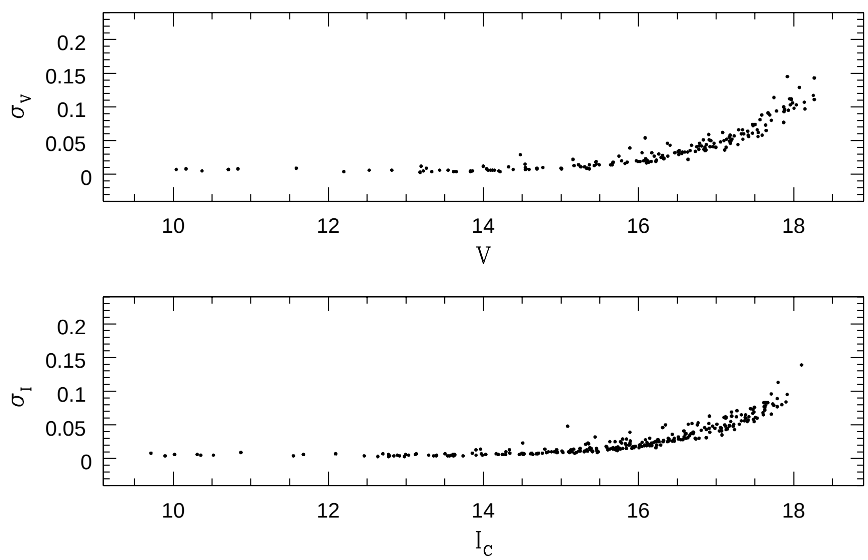

Fig. 2. Plots of *rms* magnitude as a function of V (top) and I (bottom) magnitude for stars in the region of NGC 637.

Finally, magnitudes of all stars were transformed from our instrumental system to photometry obtained by Henden (2001). Basing on the brightest common stars we calculated coefficients of transformation. Equations are the following:

$$i = I - 0.122(V - I) + 1.017 \tag{1}$$

$$v - i = 1.043(V - I) - 0.162. \tag{2}$$

Appropriate aperture corrections were derived proceeding the transformation.

3 Results

3.1 Density profile

The center of NGC 637 was found by calculating the density center for stars inside a circle of radius of 70 pixels, using an iterative procedure similar to that described by Mateo & Hodge (1986). In Fig. 3 we show the density profile for all stars brighter than $I = 17.3$. The average stellar density was calculated in successive 13.68 arcsec (18 pixels) wide annuli around the cluster center. The resulting density profile is rather noisy due to small number statistics. The smooth solid line represents a fit by the King (1962) profile:

$$f(r) = \frac{f_0}{1+(r/r_c)^2} + f_b \tag{3}$$

where f_0 is the central density, r_c is the radius of the cluster core and f_b is the background density. For NGC 637 we found as follows: $f_0 = 0.010 \pm 0.003$ stars per arcsec^2, $r_c = 20 \pm 4$ arcsec and $f_b = 0.0013 \pm 0.0001$ stars/arcsec^2. The cluster appears to be rather loose and has a small clumpy center. It is likely that some stars of the cluster are located outside our field. This may be due to the fact that *gross* stars from entire our field have consistent proper motions (*e.g.*, from a survey by Monet *et al.* 2003).

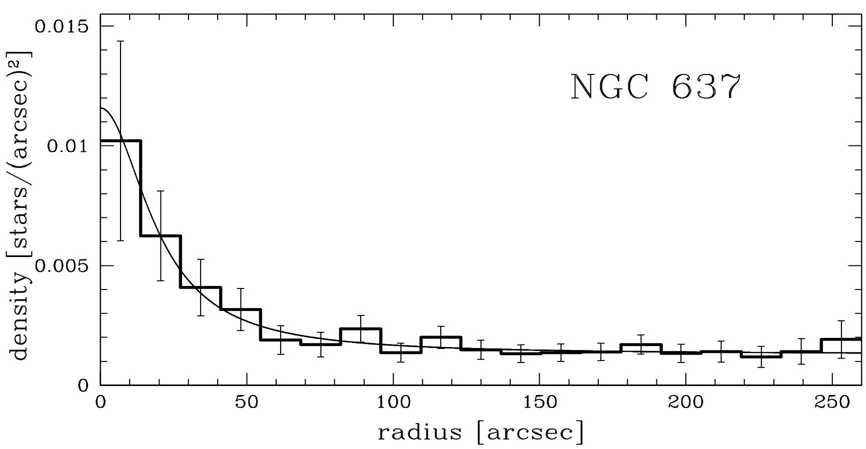

Fig. 3. Surface density distribution of stars with $I < 17.3$ from the NGC 637 field. The smooth solid line represents the King (1962) profile fitted to the histogram.

3.2 Color-magnitude diagram

Fig. 4 presents color-magnitude diagram (CMD) for the observed field with the cluster NGC 637. The morphology of CMD is typical of young open cluster. A gap in the upper main sequence, noted by Huestamendia *et al.* (1991), is also present in our data. This confirms that it does not result from incompleteness of the data.

Using theoretical isochrones published by Girardi *et al.* (2002) we are able to estimate the basic parameters of NGC 637. We fit an isochrone with solar chemical composition $(Z,Y) = (0.019, 0.273)$ and the youngest available age, 4.0 Myr. The shape of the main sequence is well reproduced for stars with $V < 17$

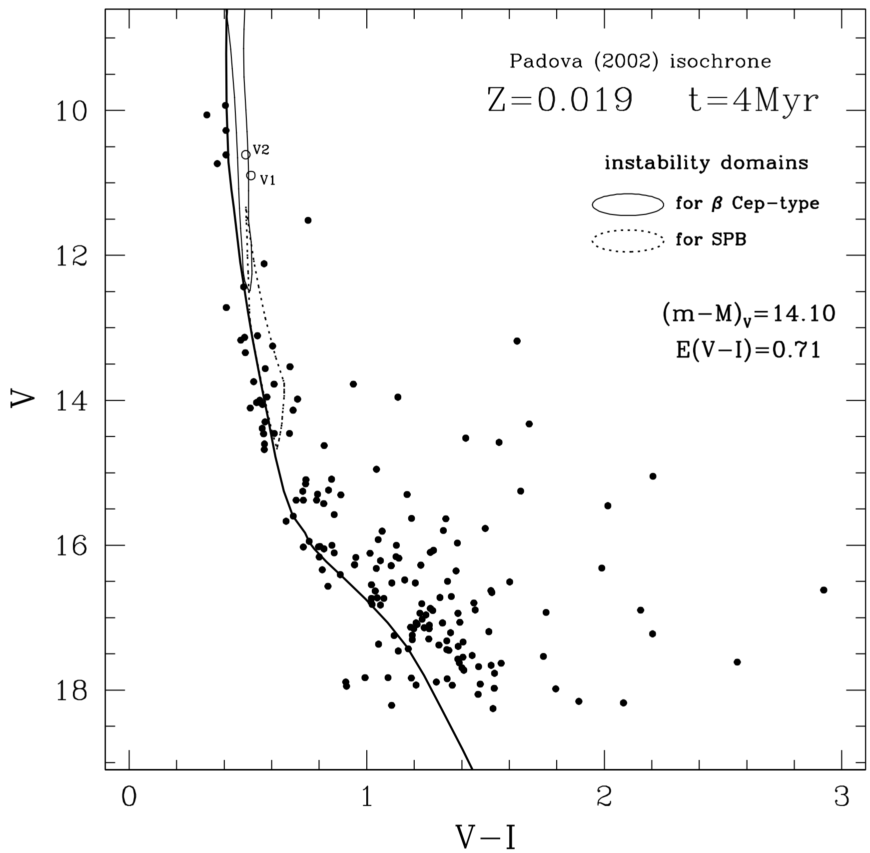

Fig. 4. $V/V-I$ diagram for NGC 637 with a superimposed isochrone and instability domains in the upper main sequence. Positions of two detected variables are denoted by small circles.

mag. We derived, by shifting the isochrone, the apparent distance modulus of $(m-M)_V=14.10$, and the reddening of $E(V-I)=0.71$. Assuming $E(V-I)=1.28E(B-V)$ we get $E(B-V)=0.55$. This value is significantly lower than the upper limit of reddening $E(B-V)=1.21$ for $(l,b)=(128.55,+1.73)$, extracted from the maps of Schlegel *et al.* (1998). We assume the uncertainty of the distance modulus as 0.2 mag, and the uncertainty of the reddening $E(V-I)$ as 0.02 mag. Adopting $R_V=3.2$ we find the minimum value of the heliocentric distance to NGC 637 as d_{min}=2.6 kpc and the maximum value as d_{max}=3.3 kpc. These numbers are consistent with the distance $D=2884$ pc given by Phelps and Janes (1994). On the other hand, our value of the reddening $E(B-V)$ differs from their value of 0.65 mag.

3.3 Variable stars

The search for variability led to the detection of two variables. They are located close to the edge of our field and are among the brightest stars (see the map in Fig. 1). Table 1 lists basic data for the new variables. Fig. 4 displays their location on the $V/V-I$ color-magnitude diagram with superimposed instability domains in the upper main sequence. The domains were computed using the OPAL opacities for the hydrogen content $X=0.70$ and metallicity $Z=0.019$

Table 1: Equatorial coordinates and photometric data for the NGC 637 variables

Name	RA(2000.0)	Dec(2000.0)	$<V>$	$<I>$	ΔV	ΔI	P_0	P_1	Type
V1	$01^{\rm h}43^{\rm m}35.^{\rm s}57$	$+64^\circ02'07.''0$	11.38	10.87	0.14	0.16	0.189991(3)	0.18917(1)	β Cep
V2	$01^{\rm h}43^{\rm m}32.^{\rm s}18$	$+64^\circ02'15.''3$	11.12	10.63	0.04	0.06	0.74316(8)	-	ell ?

(same as in Pamyatnykh 1999), and transformed to the observational values using numerical relations from Flower (1996).

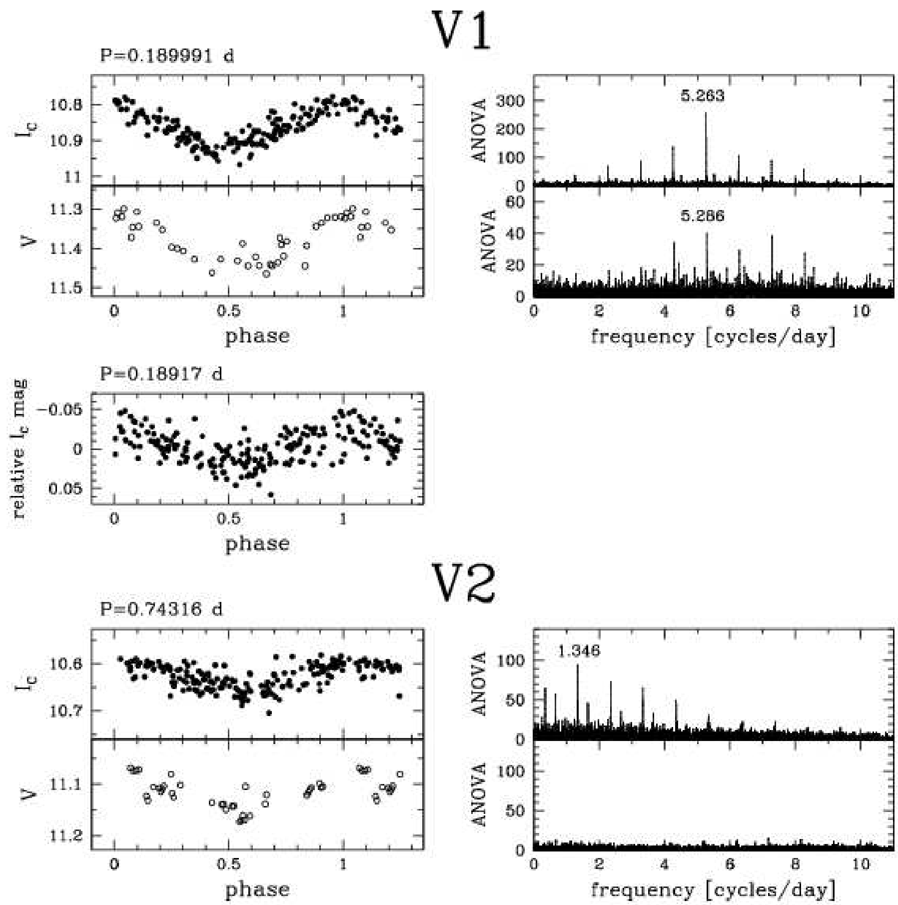

Fig. 5. Phased light curves and power spectra of two variables detected in the field of NGC 637.

Fig. 5 presents the V and I light curves of newly identified variables. The primary period of V1 is $P = 0.189991$ days. Its value, together with the position of the star on the CMD and amplitude of the light modulations, clearly indicates that V1 belongs to the β Cep-type variables.

The right panels of Fig. 5 show the ANOVA power spectra of the light curves (Schwarzenberg-Czerny 1996). The original light curve of V1 was prewhitened with main frequency and its harmonic and the resulting ANOVA statistics returned another clear periodicity of $P = 0.18917$ days. The difference between two identified frequencies is 0.023 c/d, which is over ten times larger than our frequency determination errors, and indicates that both periods are real. Such multiperiodic behavior caused by non-radial pulsations is common among β Cep-type stars (*e.g.*, Shobbrook *et al.* 2006, Schrijvers *et al.* 2004, Schrijvers and Telting 2002).

The variable V2 is even brighter than V1, being one of the brightest stars in the cluster. Its period is $P=0.74316$ days, which is typical for Slowly Pulsating B stars (SPB stars) but the variable seems to be too bright to belong to this group. The dotted line plotted in CMD shown in Fig. 4 denotes instability domain of SPB stars and clearly demonstrates that V2 is located about 1 mag over the tip of the SPB domain.

Another possibility is that V2 is in fact an ellipsoidal variable with orbital period of 1.48632 days. It is justified by small amplitude of brightness modulations and its nearly sinusoidal shape. In our opinion this is the more likely explanation.

Proper motions of the two detected variables (from *e.g.*, Kislyuk *et al.* 1999, Hog *et al.* 2000, Kharchenko 2001, Monet *et al.* 2003) suggests their membership to NGC 637.

In their paper, Huestamendia *et al.* (1991), basing on merely six observational points, remarked that their object #18 is variable. Our data do not show any variability of the object.

It is also worth noting that we searched for dwarf novae outburst in the field of NGC 637. We used the procedure described in detail by Kaluzny *et al.* (2005) and we applied it here to white light data. Result of this search is negative, which is not surprising in such a young cluster.

4 Summary

We have presented the CCD VI photometry and results of searches for variable stars in the open cluster NGC 637. The analysis of the derived color-magnitude diagram allowed us to assess some basic parameters. The apparent distance modulus for the cluster is $13.9 < (m-M)_V < 14.3$, the reddening is $0.69 < E(V-I) < 0.73$, and the estimated heliocentric distance of $2.6 < d < 3.3$kpc. The morphology of the CMD indicates that it is a young object with age of a few million years. Based on the comparison of the CMD with the theoretical isochrones, we were also not able to firmly establish the metallicity of the cluster. Spectroscopic observations would help to clarify it.

The search for variability led to discovery of two variable stars in NGC 637. One of them, V1, is a bona fide β Cep-type variable. It has two close periodicities what clearly indicates non-radial pulsations. The light curve of object V2 has nearly sinusoidal shape and small amplitude and therefore we classified it as an ellipsoidal variable. However, one can not excluded a possibility that V2 is a pulsating star.

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